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THE INFLUENCE OF SAND UPON THE CONCENTRATION AND REACTION OF A NUTRIENT SOLUTION FOR PLANTS

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Received for publication January 19, 1920

Finely divided solid substances of a certain character presenting large surfaces appear to have the power of removing salts from solution by concentrating the solute at the surface of the solid material. It has thus been shown that soils not only have the power to adsorb salts as such from solution but that this adsorption may become selective in character in that one kind of ion may be removed from solution at a more rapid rate than another kind.

Parker (6) has measured the adsorbing power of soils and has shown that the concentration of salts may be altered in contact with the soil particles. He states that a mineral fertilizer applied to the soil and dissolved in the soil solution is adsorbed either as a whole or selectively from the solution by the great surface presented by the finely divided soil particles, and is held there until the plant or subsequent leaching removes it. McCall (5) grew wheat in sand cultures and found the responses of the plants to the nutrient solutions in the sand to be different from those of similar wheat plants grown in water cultures in which the same solutions were employed. This author suggests that the salt proportions and total concentrations of the nutrient solutions may have been altered in contact with the sand particles and concludes that differential adsorption played an important rôle in bringing about the observed physiological differences. Jennings (3) found that the introduction of quartz, ferric hydroxide, and aluminum hydroxide into nutrient solutions resulted in decreased growth of wheat seedlings, and from this concludes that these substances by their adsorptive properties reduced the effective concentrations of the nutrient solutions. On the other hand, Toole and Tottingham (9), growing barley and pea plants for 21 days in Knop's nutrient solution to which had been added separately ferric hydrate, silicic acid, and carbon black, found no clear evidence of the adsorption of nutrient ions from the solutions, although their results are based upon careful chemical analyses of the treated solutions as well as upon the effect of the added solids on the growth of the plants either directly of indirectly. In a study of the effect of ammonium sulfate in nutrient solutions upon the growth of plants with sand as the solid substratum to which the solutions were added, Wolkoff (10) pointed out that the concentration values of the solutions obtained by suction from the sand in the culture pots at different times during the growth period did not vary considerably from

those of the original solutions. This author concluded that adsorption did not modify the concentrations of the solutions to such an extent as to produce even a slight influence upon plant growth.

In the study of the salt requirements of plants in sand cultures it is, of course, desirable to maintain approximate control of the salt proportions and the effective concentration of the nutrient solution applied to the sand. This is one of the chief reasons for resorting to sand cultures in investigations of this kind, since agricultural soils, when employed as substrata, always present chemical and biological complications which render adequate control of these important factors exceedingly difficult, if not impossible. It is generally considered that sand cultures present somewhat similar physical environmental conditions to those found in soil cultures, but plants grown in sand cultures are relatively free from the biological complications such as are introduced when agricultural soils are used.

It is possible that nutrient solutions supplied to sand in pot cultures may suffer not only a reduction in total concentration but also a change in the relative proportions of the constituent salts and ions as a result of contact with the solid sand particles through the adsorptive action of the solid medium. However, if ions or salts as a whole are thus removed from solution in sufficient quantities to alter the growth rates of the plants materially, it should be possible to detect the change in total concentration of the solution. A change in the reaction of the solution might also be expected when salts are removed from solution in quantities sufficient to affect the growth rates of the plants, since it is not probable that the salts or ions would be adsorbed in the same proportions in which they occurred in the solution.

The purpose of the experiments described in the following pages was to study the influence of washed sand of several degrees of fineness, and also of very fine unwashed sand, upon the effective concentration and reaction of a nutrient solution diffused as films on the solid sand particles, when the cultures were subjected to the treatment experienced in the usual course of sand culture work with frequent renewal of solutions, but in the absence of plants—since contact with the roots of actively growing plants may change the reaction of a nutrient solution very materially, especially if the contact is long continued.

METHODS OF INVESTIGATION

White seashore sand was used throughout these experiments. For the first washing the sand was placed in a graniteware tub, a little more than half filling the latter. A stream of tap water from a hose was directed into the sand, which was kept constantly agitated, until the surplus water overflowing the sides of the tub was clear and entirely free from sediment. The tap water was then drained off and the tub nearly filled with distilled water in which the sand was thoroughly washed. The wash water was drained off and the process once repeated. The washed sand was spread on large sheets of paper and allowed to become air-dry.

The air-dry sand was passed through sieves and four grades with respect to sizes of the particles were obtained. The sizes of the particles of the four different grades obtained by this mechanical separation were approximately as follows: very coarse sand, 1.5 to 1 mm.; coarse sand, 1 to 0.5 mm.; medium sand, 0.5 to 0.32 mm.; and fine sand, 0.32 to 0.25 mm. The water-retaining capacity of these four grades of sand determined according to the method described by Hilgard (2), and the values referred to the dry weight of the sand were, respectively, 26.8 per cent, 30.2 per cent, 32.4 per cent, and 37.6 per cent. These values represent the averages of four determinations for each grade.

Twelve hundred grams of air-dry sand of each of the four grades were weighed into 1-liter stoneware pots impervious to moisture, three pots to each grade of sand. The sand in each pot was then flooded with a nutrient solution for plants (solution R_3C_2 of Shive's (7) 3-salt series) of the following composition: KH_2PO_4, 0.0180m.; $Ca(NO_3)_2$, 0.0052m.; and $MgSO_4$, 0.0150m. The excess solution was drawn off through a glass tube extending through the sand to the bottom of the pot, the lower opening of the tube being screened by a plug of glass wool which served as a filter. A sufficient amount of solution was thus drawn off to leave the moisture content of the sand at 60 per cent of its water-retaining capacity in every case. Evaporation from the surface of the sand was prevented by placing the pots under small bell jars which were then sealed.

These cultures received subsequent treatment similar to that accorded to sand cultures with growing plants in the usual course of sand culture work, with renewal of solutions by the McCall (4) method at intervals throughout the experimental period. During the first interval the cultures were allowed to stand for 24 hours. At the end of this period as much as possible of the old solution was extracted, after which each culture was flooded with 250 cc. of new solution, the excess of which was again drawn off leaving the sand with its original moisture content. This process was repeated at intervals of 3, 5, and 10 days, the total experimental time covering a period of 19 days. The old solutions extracted from the cultures at the end of each interval were carefully tested for freezing-point lowerings and for hydrogen-ion concentrations. These results were compared with those of similar tests of the original solution made at the beginning of each interval.

The freezing-point depressions of the solutions were determined by the use of the Beckmann apparatus and from these the total osmotic concentration values in atmospheres were calculated after the proper corrections were made for the undercooling of the solutions. The hydrogen-ion concentration of the solutions was determined by the colorimetric method following the work of Clark and Lubs (1) as a guide in the preparation of the standard buffer solutions and in the general methods of procedure. Methyl red was found to be a satisfactory indicator for the solutions here tested.

RESULTS WITH WASHED SAND

Table 1 presents the experimental results obtained with the four different grades of washed sand. Corresponding data for very fine unwashed sand containing relatively large amounts of colloidal or semi-colloidal material will be given in another table.

In table 1 are given the hydrogen-ion concentrations (expressed as pH values) of the nutrient solutions both before and after having been diffused as films over the solid sand particles. The freezing-point depressions, corrected for undercooling, and the corresponding derived osmotic concentration values for 25°C. (measured in atmospheres) are given. The last column of the table shows the plus or minus per cent deviations from the osmotic concentration values of the original solution. The table is divided into four horizontal sections, each of which presents the complete data obtained with a single grade of sand.

It will be observed that the solutions extracted from the different grades of sand at the end of each time interval all show very close agreement with each other and with the original solution with respect to the pH values. The pH value of the original solution was 4.7 in all cases while the average pH values of the extracted solutions ranged between 4.7 and 4.8, representing hydrogen-ion concentrations not higher than 0.200×10^{-4} (pH 4.7) nor lower than 0.159×10^{-4} (pH 4.8). Three of the average pH values of the extracted solutions are equal to that of the original solution. These three are shown for the solutions extracted from the very coarse sand at the end of the 10-day interval, and for those from the medium sand at the end of the 24-hour and 10-day intervals. All the other average pH values are slightly above that of the original solution. None is lower than that of the original solution.

The fact that nearly all the average pH values are slightly above and none below that of the original solution might be regarded as indicating a slight reaction change of the nutrient solution resulting from contact with the solid sand particles. However, the very small deviations of the average pH values from that of the original solution, and the correspondingly slight reaction changes of the nutrient solution represented by them must be regarded as being without significance when considered in connection with any influence which they might have upon the growth rates of plants.

The average total concentration values (in atmospheres) of the solutions extracted from the different grades of sand, like the pH values of these solutions show very close agreement with the corresponding values of the original solution. The highest total concentration value (average of three tests) was 1.80 atmospheres, representing a deviation of 2.86 per cent above that of the original solution. This is shown for the solutions extracted from the very coarse sand at the end of the 24-hour interval. The lowest average concentration value was 1.74 atmospheres, which is 1.14 per cent below that shown for the original solution. This was the average concentration for the solutions

TABLE 1

Data for a nutrient solution before applying to and after extracting from washed sand of several degrees of fineness

DESCRIPTION OF SAND	TIME SOLUTION REMAINED IN CONTACT WITH SAND WITHOUT RENEWAL	CULTURE NUMBER	HYDROGEN-ION CONCENTRATION	FREEZING-POINT DEPRESSION	OSMOTIC CONCENTRATION VALUE AT 25°C.	PLUS OR MINUS DEVIATION FROM CONCENTRATION VALUE OF ORIGINAL SOLUTION
			pH*	°C.	*atm.*	*per cent*
Very coarse sand, 1.5 to 1.0 mm.	24 hours	1	4.7	0.133	1.75	0.00
		2	4.8	0.138	1.81	+3.43
		3	4.8	0.139	1.83	+4.57
		Average	**4.77**	**0.137**	**1.80**	**+2.86**
	3 days	1	4.8	0.133	1.75	0.00
		2	4.8	0.135	1.77	+1.14
		3	4.8	0.133	1.75	0.00
		Average	**4.8**	**0.134**	**1.76**	**+0.57**
	5 days	1	4.8	0.134	1.76	+0.57
		2	4.7	0.136	1.78	+1.71
		3	4.8	0.132	1.74	−0.57
		Average	**4.77**	**0.134**	**1.76**	**+0.57**
	10 days	1	4.7	0.133	1.75	0.00
		2	4.7	0.132	1.74	−0.57
		3	4.7	0.134	1.76	+0.57
		Average	**4.7**	**0.133**	**1.75**	**0.00**
		Original solution	4.7	0.133	1.75	
Coarse sand, 1.0 to 0.5 mm.	24 hours	4	4.7	0.131	1.72	−1.71
		5	4.8	0.135	1.77	+1.14
		6	4.7	0.140	1.84	+5.14
		Average	**4.73**	**0.135**	**1.78**	**+1.71**
	3 days	4	4.8	0.140	1.84	+5.14
		5	4.7	0.130	1.71	−2.29
		6	4.8	0.132	1.74	−0.57
		Average	**4.77**	**0.134**	**1.76**	**+0.57**
	5 days	4	4.7	0.133	1.75	0.00
		5	4.7	0.135	1.77	+1.14
		6	4.8	0.133	1.75	0.00
		Average	**4.73**	**0.134**	**1.76**	**+0.57**
	10 days	4	4.8	0.136	1.78	+1.71
		5	4.7	0.137	1.80	+2.86
		6	4.8	0.134	1.76	+0.57
		Average	**4.77**	**0.136**	**1.78**	**+1.71**
		Original solution	4.7	0.133	1.75	

TABLE 1—*Concluded*

DESCRIPTION OF SAND	TIME SOLUTION REMAINED IN CONTACT WITH SAND WITHOUT RENEWAL	CULTURE NUMBER	HYDROGEN-ION CONCENTRATION	FREEZING-POINT DEPRESSION	OSMOTIC CONCENTRATION VALUE AT 25°C.	PLUS OR MINUS DEVIATION FROM CONCENTRATION VALUE OF ORIGINAL SOLUTION
			pH*	°C.	*atm.*	*per cent*
Medium sand, 0.5 to 0.32 mm.	24 hours	7	4.7	0.135	1.77	+0.57
		8	4.7	0.144	1.89	+7.39
		9	4.7	0.133	1.75	−0.57
		Average	**4.7**	**0.137**	**1.80**	**+2.27**
	3 days	7	4.8	0.133	1.75	−0.57
		8	4.8	0.131	1.72	−2.27
		9	4.7	0.133	1.75	−0.57
		Average	**4.77**	**0.132**	**1.74**	**−1.14**
	5 days	7	4.8	0.135	1.77	+0.57
		8	4.7	0.135	1.77	+0.57
		9	4.7	0.133	1.75	−0.57
		Average	**4.73**	**0.134**	**1.76**	**0.00**
	10 days	7	4.7	0.134	1.76	0.00
		8	4.7	0.130	1.71	−2.84
		9	4.7	0.133	1.75	−0.57
		Average	**4.7**	**0.112**	**1.74**	**−1.14**
		Original solution	4.7	0.134	1.76	
Fine sand, 0.32 to 0.25 mm.	24 hours	10	4.7	0.135	1.77	+1.14
		11	4.8	0.135	1.77	+1.14
		12	4.8	0.131	1.72	−1.71
		Average	**4.77**	**0.134**	**1.76**	**+0.57**
	3 days	10	4.7	0.132	1.74	−0.57
		11	4.8	0.133	1.75	0.00
		Average	**4.75**	**0.133**	**1.75**	**0.00**
	5 days	10	4.8	0.134	1.76	+0.57
		11	4.8	0.134	1.76	+0.57
		12	4.8	0.133	1.75	0.00
		Average	**4.8**	**0.134**	**1.76**	**+0.57**
	10 days	10	4.7	0.134	1.76	+0.57
		12	4.8	0.136	1.76	+1.71
		Average	**4.75**	**0.135**	**1.77**	**+1.14**
		Original solution	4.7	0.133	1.75	

* The term pH is given to the number representing the logarithm of the hydrogen-ion concentration taken as a positive value.

extracted from the medium sand at the end of the 3-day and 10-day intervals. All but five of the average concentration values represent plus deviations from the concentration of the original solution and only two represent minus deviations. There is no regularity in the manner in which these deviations occur and all are very small so that no significance can be attached to them, especially when considered in relation to the relatively low sensitiveness of ordinary plants to slight variations in the total salt concentrations of the medium in which they are grown. Thus, with the nutrient solution here employed, with sand of different degrees of fineness, washed free from colloidal or semi-colloidal material, there is no clear evidence of the adsorption of salts or ions in sufficient amounts to alter materially the hydrogen-ion concentration of the nutrient solution or to reduce its effective total concentration measurably. This is in accord with the results of previous work (8) with washed sand, in which it was found that the physiological properties of nutrient solutions as these affected the growth rates of buckwheat plants were not materially altered as the result of direct contact with the solid sand particles.

RESULTS WITH UNWASHED SAND

The unwashed sand here employed was taken from the same supply of white seashore sand as was the washed sand used in the preceding experiments. The coarser particles of the sand were mechanically separated from the finer by means of a sieve which permitted only particles with diameters less than 0.25 mm. to pass, the coarser sand being discarded. This very fine sand contained relatively large quantities of colloidal or semi-colloidal material, as is indicated by the fact that when 100 gm. of the sand were shaken with 250 cc. of distilled water for one minute and then allowed to settle for 30 minutes, 100 cc. of the supernatant liquid contained 0.260 gm. of suspended solid material, and traces of the suspended material were still present in the supernatant liquid at the end of a week. The water-retaining capacity of this fine sand was 39.87 per cent of the dry weight of the sand.

The methods used with this fine unwashed sand were identical with those adopted in the preceding experiments with washed sand. The nutrient solution added to the sand was the same in composition and total concentration as that previously employed and this was renewed at intervals of 24 hours, 2 days, 4 days, and 3 days, covering a total experimental period of 10 days.

As before, 1200 gm. of sand were used with each culture. The series consisted of four cultures which received similar treatment, and fifth, control culture, to which distilled water was applied instead of the nutrient solution, in all other respects receiving the same treatment as the other cultures. The control culture was included in the series in order to determine to what extent the freezing point might be depressed and the total concentration of the nutrient solution correspondingly increased by soluble substances in the sand. In this it is assumed, of course, that the efficiency of the nutrient solution as a

TABLE 2

Data for nutrient solution before applying to and after extracting from very fine unwashed sand

TIME SOLUTION REMAINED IN CONTACT WITH SAND WITHOUT RENEWAL	CULTURE NUMBER	HYDROGEN-ION CONCENTRATION	FREEZING-POINT DEPRESSION	OSMOTIC CONCENTRATION VALUE AT 25°C.	PLUS OR MINUS DEVIATION FROM CONCENTRATION VALUE OF ORIGINAL SOLUTION
		pH	°C.	*atm.*	*per cent*
24 hours	1	4.9	0.122	1.61	−8.52
	2	4.8	0.121	1.59	−9.66
	3	4.7	0.123	1.62	−7.95
	4	4.7	0.124	1.63	−7.38
	Average	**4.77**	**0.123**	**1.61**	**−8.50**
	Original solution	4.7	0.134	1.76	
2 days	1*				
	2	4.7	0.131	1.73	−1.14
	3	4.8	0.129	1.70	−2.86
	4	4.8	0.130	1.71	−2.28
	Average	**4.76**	**0.130**	**1.71**	**−2.29**
	Original solution	4.7	0.133	1.75	
4 days	1				
	2	4.7	0.133	1.75	0.00
	3	4.7	0.132	1.74	−0.57
	4	4.7	0.135	1.78	+1.71
	Average	**4.7**	**0.133**	**1.75**	**+0.57**
	Original solution	4.7	0.133	1.75	
3 days	1				
	2	4.8	0.133	1.75	0.00
	3	4.7	0.132	1.74	−0.57
	4	4.7	0.134	1.76	+0.57
	Average	**4.73**	**0.133**	**1.75**	**0.00**
	Original solution	4.7	0.133	1.75	

* Through accident it became necessary to discontinue culture 1, at the end of the first interval.

solvent of the mineral constituents of the sand was equal to that of distilled water.

The numerical data of the tests with unwashed sand here used are presented in table 2. The data of this table correspond to those of table 1. The freezing-point lowerings, corrected for undercooling, as given in table 2, are the values obtained after deducting the freezing-point depression resulting from

soluble substances in the sand, determined by tests made of the extract from the sand of the control culture at the end of each interval. Thus, at the end of the first interval the extract from the control culture gave a freezing-point lowering of 0.018°C. (average of four tests) corrected for undercooling. This was then deducted from the freezing-point depressions of the solutions extracted from the sand of the other cultures, giving the values as they appear in the table for the interval in question. This was done for each succeeding interval. At the end of the second interval the freezing-point lowering of the extract from the control culture was 0.004°C. (average of four tests), but at the end of the third interval no depression of the freezing point, below that of the distilled water used, could be detected. Thus, while the sand at first contained small quantities of soluble matter, this was removed with the successive renewals of the distilled water in the control culture, so that after the second renewal no more soluble substance remained, in so far as this could be detected by means of the freezing-point method.

Inspection of table 2 shows the pH values of the solutions extracted from the sand to be in very close agreement with those of the original solution. Three of the four average pH values are slightly higher and one is equal to that of the original solution. As in the preceding experiments with washed sand there is here no evidence of marked change in the reaction of the nutrient solution which might be attributed to adsorption phenomena resulting from direct contact of the solution with the solid sand particles.

The solutions extracted from the sand at the close of the first and second intervals show consistently lower total concentration values than do those of the original solution. The average of these values for the first interval is 1.61 atmospheres, representing a deviation of 8.50 per cent below that of the original solution. The corresponding average for the solutions at the end of the second interval is 1.71 atmospheres, representing a minus deviation of 2.29 per cent, but at the end of the third interval the average total concentration of the extracted solution is 1.76 atmospheres, this being a deviation of 0.57 per cent above that of the original solution.

The fact that the total concentration values of the solutions extracted from the sand at the end of the first and second intervals are consistently lower than that of the original solution, is fairly clear evidence that the adsorptive capacity of the sand is here effective in reducing the total concentration of the solution, although this reduction was not large even during the first interval. With the second renewal of solution at the beginning of the 4-day interval, it appears that equilibrium was established with respect to the adsorptive capacity of the sand, that is, the ability of the sand to adsorb salts from this solution had reached its limit, therefore no reduction in the total concentration occurred when the solution was again renewed.

As already brought out, the results obtained with washed sand gave no evidence of any reduction in the total concentration of the nutrient solution applied to the sand which might be attributed to adsorption. The observed

reduction in the total concentration of the solution added to the unwashed sand here used is, therefore, to be ascribed to the adsorptive action of the finely divided, colloidal or semi-colloidal material which was removed from the sand in the process of washing.

The greatest reduction in the total concentration observed is 0.17 atmospheres, representing a minus deviation of 9.66 per cent of the concentration of the nutrient solution added to the sand. Considering the relatively low sensitiveness of agricultural plants to slight variations in the total salt concentration of the medium in which they are grown, even such a reduction in the total concentration of a nutrient solution when added to sand in sufficient quantities to give optimum moisture content, is scarcely sufficient to produce any marked changes in the growth rates of plants so long as the concentration is well within the range required for good growth and the solution is frequently renewed by some method such as that devised by McCall (4), or by some other adequate method. If, on the other hand, the total concentration of the nutrient solution added to the sand should be considerably below that required for approximately optimum growth it is readily to be seen that even a slight reduction in the effective concentration, or a change in the salt or ion proportions through differential adsorption might have a very marked effect upon the growth of plants already suffering from an inadequate salt supply.

Perhaps the most noteworthy feature brought out in these tests is the fact that by removal from the sand of the very finely divided colloidal or semi-colloidal material by thorough washing in flowing water which carried away this material in suspension, the power of the sand to adsorb salts from the nutrient solution used was eliminated, in so far as any change in total concentration or reaction could be detected by the methods here employed. It thus appears that in culture work with washed sand, alteration of the physiological properties of nutrient solutions (such as was here used) by the adsorptive properties of the sand, sufficient to influence the growth rates of plants, is not to be expected when the solutions are diffused as films on the solid particles of the substrata. It further appears that frequent renewal of solutions will soon overcome any initial adsorptive effects of very fine sand containing considerable quantities of colloidal or semi-colloidal material, by saturating the adsorptive capacity of the sand.

SUMMARY

A study was made of the influence of washed sand of four different degrees of fineness, and also of very fine unwashed sand, upon the reaction and concentration of a nutrient solution. The solution was applied to the sand in culture pots to give a moisture content of 60 per cent of the water-retaining capacity of the sand in every case. The solution was renewed at stated intervals after as much as possible of the old solution had been extracted from the sand by suction. Tests were made of these solution samples for the

hydrogen-ion concentration and for the total salt concentration and the results of these tests were compared with those of similar tests of the original solution.

1. With the different grades of washed sand there was no evidence of the adsorption of salts or ions in sufficient amounts to alter materially either the reaction or the total salt concentration of the solution in contact with the solid particles of the substrata.

2. The adsorptive capacity of the unwashed sand was sufficient to reduce the total salt concentration of the solution from 1.76 atmospheres to 1.61 atmospheres (average reduction of 8.50 per cent) during the first 24-hour interval.

3. The reaction of the nutrient solution was not markedly altered by contact with the unwashed sand.

4. By renewal of the nutrient solution the initial adsorptive effect of the unwashed sand was soon eliminated, apparently by saturating its adsorptive capacity.

5. The adsorptive properties of the unwashed sand appeared to be due to the very finely divided colloidal or semi-colloidal material which was removed from the sand in the process of washing.

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EXPERIMENTS ON THE VALUE OF COMMON ROCK SALT AND SULFUR FOR KILLING LIVE STUMPS[1]

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INTRODUCTION

The clearing of land in New Jersey, where great tracts of valuable land are covered with pine and oak woods, is commonly accomplished both by the method of "suckering" and with the help of goats. Suckering is tedious and expensive. A woodlot which is to be cleared is usually cut down close to the ground and the brush piled in large heaps and burned at the place. The next spring the "suckers" start and grow vigorously, because the live stumps have an extensive root system which enables them to send out new shoots over and over again. During the spring and summer these stumps are "suckered" two or three times. This suckering consists of breaking down as many as possible of the new shoots, and woodcutters believe that this is especially effective during the month of August. However, the other work on the farm during this month does not always allow the men to do this work as thoroughly as it should be done to make it effective. Besides, great numbers of branches cut down even in August make new sprouts again the following spring. It therefore often takes several years before the land is brought into such a shape that these stumps do not hamper the crops growing among them. The dead stumps are removed later when the time is opportune. Clearing with the help of goats proceeds in the same way, except that the thick woodlots are often first "opened up" by the goats before the tall trees and heavy underbrush are cut down. Later the suckers are kept down by the grazing goats.

To find a means whereby the clearing would be less costly and whereby the land could be improved, possibly after one or two years, was the object of the work recorded below. In order to study the effects of salt and sulfur in killing live stumps, a number of woodlots in different parts of the state of New Jersey were selected. The most extensive of these were at New Brunswick, Bridgeton, and New Lisbon; the first one being on the College Farm, the second on the farm of Mr. L. H. Sharp at Bridgeton, and the third at the Four

[1] This work was suggested by Dr. Jacob G. Lipman, director of the New Jersey Agricultural Experiment Station, and started in coöperation with the Forest Service of the State Department of Conservation and Development.

Mile Colony of the Burlington County Farm for feeble-minded children.[2] The experiments therefore, were carried out under somewhat different climatic and soil conditions. The soil at New Brunswick consists of a mixture of Sassafras loam and Pennsylvania loam, and is rather swampy. The soil at Bridgeton is a sandy loam, and that at New Lisbon is a dry sandy soil. The experiments were started early in the spring of 1919. Other experiments, to determine whether there is a pronounced difference due to seasonal influences, were started during the year.

EXPERIMENTS WITH SALT ON A SWAMPY SOIL NEAR THE AGRICULTURAL COLLEGE AT NEW BRUNSWICK

Twelve plots, with from fifteen to seventeen good-sized stumps, were marked off. The species of tree stumps were oak (black and white), birch, maple, dogwood, chestnut, and cherry. The height of the sprouts in the spring varied from 10 to 18 feet. The amounts of salt applied on the various plots were as follows:

PLOT NUMBER	SALT PER ACRE	PLOT NUMBER	SALT PER ACRE
	lbs.		*lbs.*
101	420	107	2500
102	840	108	3000
103	1250	109	3350
104	1650	110	3750
105	2100	111	4200
106	2100	112	4200

The applications were made on or around the stumps, except on the two plots (106 and 112) receiving applications of 2100 and 4200 pounds per acre, respectively, which were scattered broadcast. According to analyses made, the common rock salt which was used contained 97 to 98 per cent sodium chloride, a little magnesium chloride, and a few impurities. The salt was applied on April 3, 4 and 5, after several days of dry weather. Heavy rains during the next few days dissolved a great deal of the salt, but the remainder formed a crust which required a long time to dissolve. Even in midsummer, traces of the salt could be found under the trees which had made a more or less vigorous growth. The luxuriant foliage of the oak trees, especially, prevented dissolving.

The tree stumps were examined frequently during the summer months. Up to the last of July not much effect could be detected. An examination made in the middle of August gave the results as recorded in table 1. A later exam-

[2] The writer is indebted to Mr. W. M. Baker, assistant forester of the State Forest Department, and to Mr. W. W. Oley, county agent for Cumberland County, for their cheerful help in the laying out of the plots and the applying of the salt and sulfur; also to Mr. L. H. Sharp for placing the land at our disposition.

ination, made on September 5, showed that on plot 105 a small birch had died. Some of the higher branches of small maples were dying but the roots had sent out vigorous new shoots.

The effect of the salt upon these stumps of high trees, with their vigorously growing shoots, was very limited in this swamp. The larger stumps were

TABLE 1

Effect of salt treatment as recorded in the middle of August

PLOT NUMBER	HEIGHT OF SPROUTS	SALT APPLIED PER ACRE	CONDITIONS NOTED
	feet	*lbs.*	
101	10 to 18	400	Oaks have deep blue-green leaves and appear abnormally vigorous. Birch thrifty. Chestnut healthy
102	9 to 16	800	Oak, maple, and cherry healthy. Oak leaves not so blue-green as on plot 101, but seem to be larger
103	9 to 15	1250	Oak, birch, maple, and dogwood healthy. Nothing unusual to be detected
104	9 to 15	1675	Oak and maple healthy. Birch slightly injured; birch leaves have brown edges
105	9 to 16	2100	Oaks healthy. Maples injured; leaves are small and shriveled. Some birch slightly injured
106	8 to 15	2100*	Small maple killed. Dogwood injured. Some birch slightly injured, others healthy. Some oaks very slightly injured, others healthy
107	9 to 15	2500	Small maple killed. One birch killed, others injured. Dogwood badly injured. Oaks healthy
108	9 to 16	3000	A few maples and birch killed, others injured. Cherry slightly injured. Oaks healthy
109	8 to 16	3400	Birch and dogwood injured; leaves turning yellow and falling. Small maple killed. Large maple injured. Oaks healthy
110	9 to 15	3800	Birch and dogwood injured. Small maple killed. Oaks healthy
111	9 to 16	4200	Maple killed. Some birch injured, others killed. Pear and cherry killed. Oaks healthy. None of the large stumps killed, only slightly injured or healthy
112	9 to 16	4200*	Small maple killed, others injured. Dogwood injured. Some birch injured. No effect on oaks to be detected

* Scattered broadcast.

only slightly, if at all, injured, and but few of the smaller stumps were killed. The resistance of the stumps to treatment with salt was apparently in the order of oak, cherry, chestnut, dogwood, birch, maple, the last named being affected most intensely and most easily. This would be expected if the hardiness of the wood is taken into consideration.

EXPERIMENTS WITH SALT AND SULFUR

The experiments at Bridgeton were conducted on land to be cleared for truck farming. The soil is a sandy loam. The treated plots were approximately $\frac{1}{17}$ acre, with check plots four times as large at either end of the group of treated plots. The land was cleared in the same way as is done by the practical farmer: the trees and brush were cut down and the branches burned on the ground. A counting made of the number of stumps on these plots placed the average at 45 good-sized stumps. The very small stumps were not included. Nearly all the stumps were black and white oak. About a week after the brush was burned, the salt and sulfur were applied in the following amounts:

	SODIUM CHLORIDE (POUNDS PER ACRE)			SULFUR (POUNDS PER ACRE)			
Applications made May 15, 1919, on or around the stumps							
Check plots	*No. 1* 1000	*No. 2* 1600	*No. 3* 2100	*No. 13* 90	*No. 14* 180	*No. 15* 350	Check plots
	No. 4 2600	*No. 5* 3200	*No. 6* 3750	*No. 16* 500	*No. 17* 700	*No. 18* 850	
	No. 7 4200	*No. 8* 4750	*No. 9* 5300	*No. 19* 1000	*No. 20* 1300	*No. 21* 1725	
Applications made May 15, 1919, scattered broadcast							
Check plots	*No. 10* 3200	*No. 11* 4200	*No. 12* 5300	*No. 22* 750	*No. 23* 1000	*No. 24* 1500	Check plots

An examination made on July 2 showed that the growth of the suckers on plots 1, 2 and 3 was markedly retarded, while the suckers on the stumps of plots 4, 5, 6 and 7 were not only retarded, but injured and in some cases killed. On the two plots where the heaviest applications had been made, plots 8 and 9, nearly all suckers were killed, and those left on the stumps had a sickly appearance. Very small stumps, apparently not touched by the salt when the applications were made, showed a healthy growth on these plots.

The plots on which application had been made broadcast, plots 10, 11 and 12, were also affected. The huckleberry brush was killed, and some of the suckers which remained on the stumps had a sickly appearance; but the effect was by no means so marked as on the plots which received the same amount of salt, applied on and around the stumps. A very marked line was to be seen between the check plots and the treated plots, even at places where the smallest applications were made. The height of the suckers was much less on the treated plots, and the number markedly decreased.

An examination made on September 26 showed that oaks which were still growing on plots 7, 8 and 9 looked sickly. Their branches were much shorter

and the leaves were small. The same was observed on the plots where salt was scattered broadcast (plots 10, 11 and 12), while the growing branches on the stumps on plots 1 to 6, where the smallest amounts were given, had a sickly appearance. In general, the leaves of the oaks on all treated plots were brownish and partly withered, while the leaves of the oaks on the check plots appeared to be healthy, with no signs of autumn to be detected as yet. On the treated plots much mildew was found, but on the check plots very little. The same was observed on a cutover land of about 15 acres where the stumps were allowed to grow throughout the entire year; here the leaves were only slightly attacked by the mildew. The sickly leaves which had brown edges and were shriveled or curled, dropped from the branches when slightly touched. The branches themselves were easily removed from the stumps when pushed down slightly, or when touched by walking past. This was not the case with branches on stumps on the check plots. These easily removable branches had a bluish black pith, indicating toxicity. This bluish black color in the center of the stems gradually decreased toward the top of the shoot, the darkest color being nearest the stump. Laboratory and other field experiments seem to indicate that when the sodium chloride is dissociated by the soil moisture and rain-water, the chlorine ion is taken up by the roots, causing toxicity. This chlorine is distributed throughout the plants, carried to the extreme end of the tracheids in the leaves or to the ends of the secondary veins, causing the brown discoloration of the leaves.

Examinations at the same time of the plots on which sulfur was applied, showed that even at the end of the season a part of the sulfur had not dissolved. Where heavy applications were made (plots 19, 20, 21, 23 and 24) the growth appeared to be slightly retarded, while on the plots where small applications were made a slight stimulating effect was noticeable. A comparison made between the plots which had received 1000 and 1600 pounds of salt per acre and the plots which had been given at least the same amount of sulfur showed that the retarding effect of the salt was markedly greater. In fact the only difference which was to be seen between the plots with the heaviest sulfur applications and the check plots, was that on the former the average length of the branches of the oak stumps appeared slightly shorter than on the latter. On a number of stumps in the plots which had received the heaviest sulfur applications it was found that some of the leaves on the lower parts of the stems had wilted and some had dropped off. Mildew had attacked the leaves on these plots much more severely than on the check plots, but much less than on the salt plots.

A series of experiments were conducted in exactly the same way near New Lisbon. Here, however, the brush from 13 to 18 feet high was not cut down, but the applications were made without disturbing the growth of the stumps. Examinations made during the summer and fall showed that the influence of the salt was very slight. No injurious effect upon the growth could be observed, but where the smallest applications were made a more or less marked

stimulating effect appeared. The leaves of the high branches of the stumps on these plots were more glossy, darker in color, and larger. Where the heaviest applications were made, only slight discoloration of the leaves occurred, not enough to prevent, or even retard the growth of the stems. In the case where sulfur was applied the majority of the stumps seemed to be stimulated rather than retarded in every instance. Not all of the sulfur was dissolved when the last examination was made.

A number of experiments of a similar nature were conducted throughout the state of New Jersey to determine the most opportune time of application. Salt and sulfur applications which were made in the summer did not dissolve rapidly enough to be toxic, while applications made in early fall, when the stumps had ceased growing, had little or no effect.

CONCLUSIONS

Application of sulfur on high or low oak brush, as a means of clearing land for agricultural purposes, is of no value. Instead, sulfur seems to have a stimulating effect upon the growth of live tree stumps.

Common rock salt, when applied to oak stumps which have been allowed to grow for several years, does not do much harm when applications of from 2 to 2½ tons per acre are given. When applied in amounts of ½ to 1 ton per acre, these shrubs are stimulated, the salt acting as a fertilizer.

In cases where trees have been cut in winter time and the brush burned at the place, the stumps are much retarded in their growth by applications of salt at the rate of ½ to 1½ tons per acre. If applications of 2 to 3 tons per acre are made, stumps of white oak and black oak are killed or so severely injured that death results.

The best time to make salt applications is in the spring, just before the leaves appear and when the sap stream is able to carry the chlorine to the buds and young leaves.

PLATE 1

FIG. 1. Cleared land in early spring when the applications were made. In the foreground, scattered broadcast; in the background, application on and around the stumps.

FIG. 2. Same field in September. The application was approximately 2 tons of common rock salt per acre, on and around the stumps.

FIG. 1

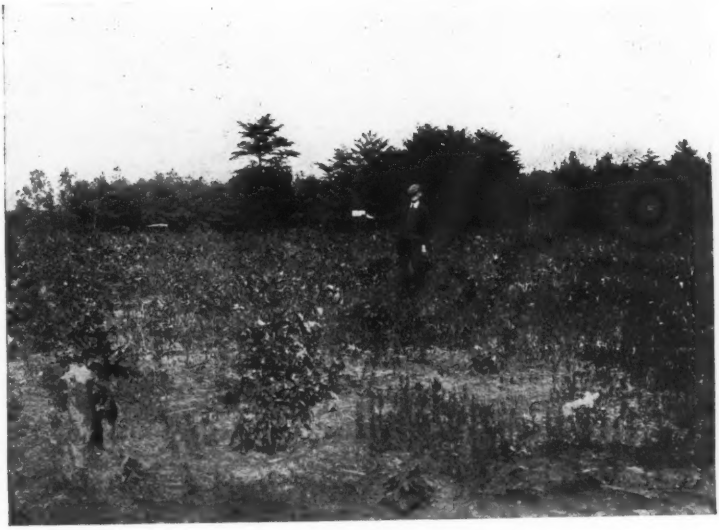

FIG. 2

PLATE 2

FIG. 1. Plot which received approximately 2 tons of salt per acre, scattered broadcast.
FIG. 2. Check plots.

FIG. 1

FIG. 2

A NEW SOIL ELUTRIATOR

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INTRODUCTORY

Briggs (1, 2) pointed out many years ago that the geometrical configuration in a soil consists of tortuous liquid-solid, liquid-gas, and gas-solid surfaces intersecting and meandering in devious ways. Such configuration, usually and perhaps never at equilibrium, may be expected, from the purely mechanical point of view, to be controlled primarily by the effective size of the particle, the coefficient of viscosity (η) of the liquid and the surface tension (T) of the liquid-air surface, although, as Briggs states, the resultant at the curve of intersection involves two additional vectors. The pressure of a liquid under a curved surface involves the surface tension (T) and the curvature of the surface, the latter depending primarily upon the "degree of dispersion"[1] of the solid phase, or the effective radius of the soil particle. Colloidal substances move with the liquid and may temporarily be ignored, except in so far as they may affect the viscous constant. It is apparent, therefore, that a complete general solution of such problems as the movement of capillary moisture in a soil may be available, involving such parameters as may be used to define the "dispersion" of the solid phase, i.e, the mean, the mode, and the average deviation of the grams-radius distribution function, the surface tension (T), and the curvature of the liquid-air surface, the latter involving the "dispersion" parameters as well as the two other surface tension constants.

The author (3) has proposed a tentative general solution of the problem of capillary flow, following in part the solution of Slichter (4) for underground water. Slichter's solution, however, does not involve a liquid-air surface. A capillary transmission constant has been introduced which involves implicitly the parameters above named, the ratio $\left(\frac{T}{\eta}\right)$ affecting this constant as a linear factor. A laboratory investigation is under way at the Utah Agricultural Experiment Station with the view of investigating the influence of this ratio, and additional plans are being made for investigating the influence of the "dispersion" parameters. It was found, however, that neither suitable

[1] This term is borrowed from Colloidal Chemistry and perhaps not incorrectly applied to the rigid soil particles.

soil separates nor a method of obtaining them in quantity were available and it is the primary purpose of this article to describe what promises to be a successful piece of apparatus for obtaining appropriate soil separates, though involving little that is essentially new in principle.

DESCRIPTION OF ELUTRIATOR

The diagrammatic sketch of figure 1 will convey at once information as to the nature of the process involved. A steady stream of muddy water is introduced at the bottom of the smallest of a series of 19 cylindrical vessels ranging in diameter in arithmetic progression from 4 to 40 cm. The stream leaves the first cylinder through a conical cap, entering the second through a conical base, and so on throughout the series.

The apparatus was constructed for our laboratory by the Central Scientific Company, the cylinders being made of brass with glass windows and detachable cap and base. Small glass cylinders were subsequently attached at the base of each cylinder through perforated rubber stoppers to serve as storage reservoirs for the particles which, contrary to original expectation, were found constantly descending into the narrow part of the conical base. In order to provide an escape for air accidentally entering the apparatus and in order that the samples collected from the tubes might be rewashed, the top of each cylinder was made to open into a vertical glass tube terminating with a funnel. Each sample can thus be readily drained off through a rubber tube attached at the lower end of the reservoir and introduced into the funnel next preceding the cylinder from which it was taken.

A stream of clear water kept constant by a simple constant head device is introduced into an appropriate vessel (*A*, fig. 1) into which the heterogeneous soil is periodically introduced and kept agitated by an electrically driven stirrer. The muddy water overflows into funnel no. 1, entering the elutriator as stated. In rewashing any of the several separates the stirring apparatus may be readily washed by draining through a tube at the bottom and the separate introduced in place of the heterogeneous soil, overflowing into the funnel immediately preceding the cylinder from which it was taken.

It is apparent that the absolute diameter of the tubes with a given current fixes the size of the particles and the size of the current fixes the rate at which soil may be handled. For the case described below a current of approximately 0.7 liter per minute was used. The velocity of the constant stream varies inversely as the square of the diameter of the cylinder,

$$v_1 = \frac{K^1}{d_1^2}$$

whereas the relative velocity of the falling particle, according to Stokes' law, is proportional to the square of the diameter of the particle,

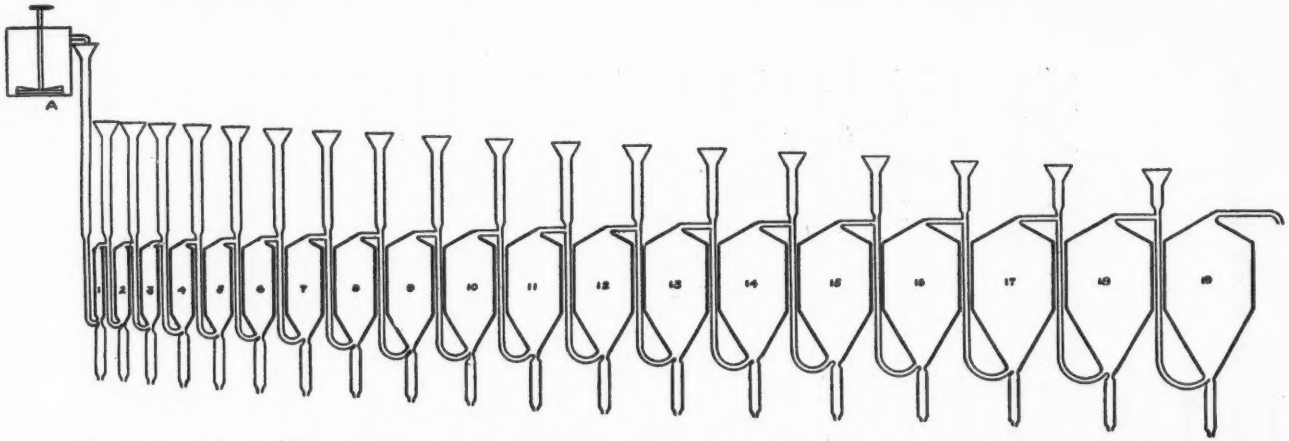

FIG. 1. DIAGRAMMATIC SKETCH OF ELUTRIATOR SHOWING COMPLETE SERIES OF NINETEEN UNITS, TOGETHER WITH FEEDING AND STIRRING DEVICE SHOWN AT *A*

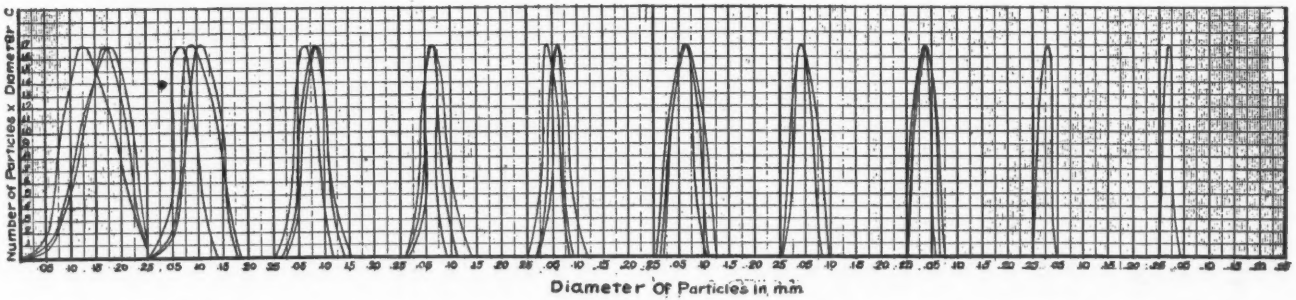

FIG. 2. PLOT OF THE GRAMS-DIAMETER DISTRIBUTION FUNCTION FROM ACTUAL COUNT AND MEASUREMENT WITH THE AID OF THE MICROSCOPE
Samples analyzed taken from units 1–7, 9, 14, 19

$$v_2 = k_2 d_2^2.$$

When the velocity of the water, v_1, is equal to the velocity of the particle, v_2,

$$\frac{k_1}{d_1^2} = k_2 d_2^2$$

and

$$d_1^2 d_2^2 = k_3$$

where d_1 and d_2 are the diameters of the cylinder and soil particles, respectively. Since, therefore, the diameters of the cylinders increase in arithmetic progression it is apparent that the diameters of the particles will diminish in harmonic progression.

The diagram of figure 2 represents the plot of the grams-radius distribution function or mechanical analysis made by actual count with the aid of the microscope of the soil from each tube of the series after a first, second, and third elutriation. The soil used contained very little organic matter and a large part of the clay had been previously washed out, so that with the mechanical stirring device described the aggregates were readily disintegrated before the muddy stream was introduced into the apparatus. The ordinate represents the product of the number of particles of the respective diameters and the cube of the diameters, the abscissae representing a range of 0 to 0.25 mm. For each tube the distribution function was determined approximately for each of the three elutriations, and a slight shift of the curve is observed in most cases after each washing, as well as a decided narrowing of the area under the curve. Under observation with the microscope a decided improvement was noticed after the second washing, as may also be seen from the microphotographs shown in plate 1, these photographs being arranged horizontally in order of changing size and vertically in order of elutriation. Since, however, the cube of the diameter was plotted as ordinate in order to harmonize with the usual method of making a mechanical analysis, the change is less noticeable on the graph. Several of the units after no. 7 were missing, but the modes of the respective curves were found to fall approximately in their proper places in the harmonic series one-fourth, one-sixth, one-eighth, etc., lending incidental support to the application of Stokes' law in this case.

The apparatus has given excellent satisfaction for our purpose, although as stated several units of the series after the seventh are missing from the set now in use. It is only accidental that a choice of diameters increasing in arithmetic progression was made, but in view of the fact that the influence of the diameter of the particle on the physical properties of the soil becomes increasingly important as the diameter diminishes, it is possible that the harmonic ratio may prove entirely appropriate.

In conclusion, acknowledgment should be made to Mr. N. E. Edlefsen and Mr. Scott Ewing for able assistance and valuable suggestions that have

been offered, and to Dr. F. L. West, head of the Department of Physics, for coöperative encouragement during the progress of the work.

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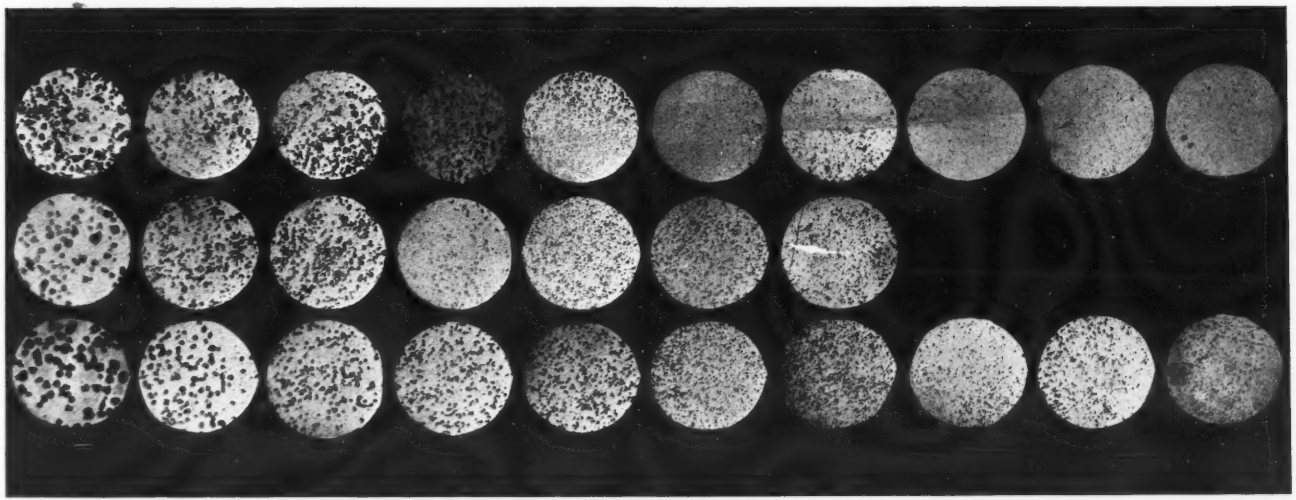

PLATE 1

MICROPHOTOGRAPHS OF SOIL PARTICLES FROM THE RESPECTIVE UNITS OF THE ELUTRIATOR AFTER A FIRST, SECOND, AND THIRD ELUTRIATION

The photographs are arranged horizontally in order of diminishing size of particle and vertically in order of elutriation. Photographs were not available for the finest particles after the second elutriation.